SUBJECTIVE AND PHYSIOLOGICAL INDICATORS OF FATIGUE IN A VIGILANCE TASK

Henry Edgar Innes

NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

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by

Henry Edgar Innes

Thesis Advisor: Douglas E. Neil

March 1973

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Henry Edgar Innes
Lieutenant Commander, United States Navy
B.S., University of Florida, 1960

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the
NAVAL POSTGRADUATE SCHOOL

March 1973

ABSTRACT

This research represents an investigation to determine intra-correlations among physiological parameters, a subjective rating of fatigue and performance during a vigilance task. Simple and multivariate analyses indicate positive relationships between subjective ratings of fatigue and heart rate, neck muscle tension level and two measures of sinus arryhthmia. Subjective ratings were found to correlate with time-on-task. Effects of motivation on sinus arryhthmia are discussed in the context of information processing. Single variate correlations between performance and heart rate, as well as with subjective ratings of fatigue, were observed with significant but low correlation coefficients. Multivariate correlation of neck muscle tension level and sinus arryhthmia were found to be significantly correlated with performance.

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I. INTRODUCTION

The use of labor-saving devices and automation has changed the nature of the task performed by the human operator in many man-machine systems. The operator is finding that his role in the system is becoming one of monitoring the performance of the system rather than that of control. However, the role that subjective fatigue of the human operator plays in the level of performance of the system is of continued, if not greater, importance.

As the nature of the human role has changed, so has the nature of his fatigue. As the operator has become more of a monitor of the system, his expenditure of energy has decreased, resulting in a decrease in the physical demands of performing the task. Performance degradation, however, remains a characteristic of the man-machine system despite the reduced physical costs imposed. This has prompted the view that one of the primary factors affecting performance in low-level energy expenditure tasks is mental fatigue /McFarland, 1971/. When viewed in light of a vigilance task, performance, or the detection and/or recognition of signals, is treated as an index of the level of operator alertness. The establishment of correlates of alertness, in vigilance type tasks, independent of performance measures, is desirable for the prediction of performance, monitoring of observers and the design of future equipments and displays.

Physiological measures have been investigated in an attempt to obtain an indicator or predictor of the level of alertness, fatigue, and/or performance degradation in tasks requiring low-levels of energy expenditure with varying degrees of success. Among the physiological

measures investigated, muscular tension associated with sustained attention [McFarland, 1971], neck muscle tension level, and skin conductance [Eason, Beardshall and Jaffee, 1965] have been shown to be of some particular value. While, in general, heart rate has not proved to be a reliable indicator of performance [Eason, Beardshall and Jaffee, 1965; Andreassi, Rapisardi, and Whalen, 1967]; changes in the heart rate in anticipation of a monitored stimulus has been observed to offer an indicator of alertness [Kibler, 1967].

Bartley (1965) has defined subjective fatigue as: "... an experienced self evaluation ....the aversion to activity....the individual's assessment of his condition with reference to his immediate task...." In light of this more personal and subjective approach, Snook and Irving (1969) and Yoshitake (1971) have shown a relationship between subjective ratings of fatigue and measures of performance on a low-level energy expenditure task.

In recent studies extending the work of Kalsbeek (1968), sinus arryhthmia, i.e., normal rhythm of cardiac activity characterized by alternating periods of rapid heart rate with periods of slower heart rate, has been shown to be responsive to information processing load and motivation [Bonsper, 1970; Ettema and Zielhuris, 1971; and Douglas, 1972]. These results suggest the possibility of using an index of sinus arryhthmia as an indicator of the level of alertness or attention.

Thus, there has been some success in the search for a means to accurately correlate physiological measures with vigilance performance, however, this research has not been entirely conclusive.

Recently multivariate analysis has been applied in an attempt to identify the relationships existing between: (a) combinations of physiological parameters, (b) task performance, and (c) subjective

fatigue and level of attention [Tinsley, 1969]. It also seems reasonable to consider the interaction of psychological parameters, human performance and the behavior of physiological activity.

Accordingly, the purpose of this research was to investigate psychophysiological parameters and subjective reports of fatigue as they relate to performance in a vigilance environment. To that end, a 90 minute vigilance task was undertaken by nine subjects. The physiological measures of heart rate, sinus arryhthmia, and neck muscle tension level were continuously recorded. Subjective ratings of fatigue were obtained from each S at the end of each 15 minute session of the task. Performance measures were recorded for each session. To restrict the index of sinus arryhthmia to reflecting only motivational levels, the information loading and processing rate were maintained constant throughout the experiment.

Simple correlation and multivariate analyses were used to attempt to identify any relationship(s) existing between the physiological parameters, performance measures and the subjective reports of fatigue.

II. METHOD

Subjects (S) were required to monitor a display of five light assemblies. The brightness of all five lights was constant and equal throughout the experiment, except during randomly spaced periods when one of the lights was brighter. A "signal" consisted of a stimulus period when one of the lights was "brighter." The differential in intensity between signal and non-signal lights was established in preliminary testing as that necessary to provide a detection proficiency of 90%. During the course of the ninety minute experiment, each S monitored 600, one-second stimulus periods. Each stimulus period was preceeded by an eight second interval during which all lights were off. For a correct response to a signal the S was required to push a button with his right hand during the one-second stimulus period in which the signal appeared. Any responses made during the eight second interval between stimulus periods was recorded as an incorrect response, as were any responses during a non-signal period. The nominal proportion of signal periods was established at 25%, yielding 150 expected signals over the entire task.

Eight male Naval officers and one male civilian served as subjects. All were volunteers from among associates of the experimenter. None had previously performed a vigilance task of this nature.

A. APPARATUS

The equipment used during the course of this experiment can be grouped in three general categories: (1) that used to form the vigilance task; (2) that required to record performance; (3) and that used for the monitoring of the physiological characteristics of the Ss.

1. Performance.

The vigilance task undertaken by each S consisted of monitoring a display of five General Electric GE47, six volt, light bulbs, each enclosed within an aircraft instrument warning light module with a red filter cover. The light assemblies were mounted on a 12 inch square display board in a cross pattern with three and one-half inches between assemblies (Figure 1). The display was mounted in a near-vertical position approximately 32 inches from the Ss and 12 to 14 inches below eye level. The Ss monitored the display inside an Industrial Acoustics Company acoustical chamber (Figure 2). Ambient illumination was provided by a 15 watt incandescent lamp.

The display was programmed to illuminate all five lights simultaneously for the one second stimulus periods, and to provide an eight second interval between stimulus periods. During randomly selected stimulus periods, one of the lights would be illuminated at a higher intensity than the remaining four lights. Each stimulus period was independently given a probability of .25 of becoming a signal period by use of a randomizer contained in the power circuits for the lights. The selection of the signal stimulus periods and the timing circuits were provided by use of a Lehigh Valley Electronics Company Solid State Logic assembly. An Ohr-tronics Inc. Model 119 Paper Tape Reader was used to read a series of random integers (1,2,3,4 and 5), programmed uniformly on a paper tape to select the light, and to provide the signal during a signal stimulus period. Electrical output from the tape reader opened a relay in the electrical power circuit of the light selected to provide the signal. The opened relay bypassed an adjustable resistor, thereby allowing greater current to reach the selected bulb and causing it to appear brighter. The circuits involving the

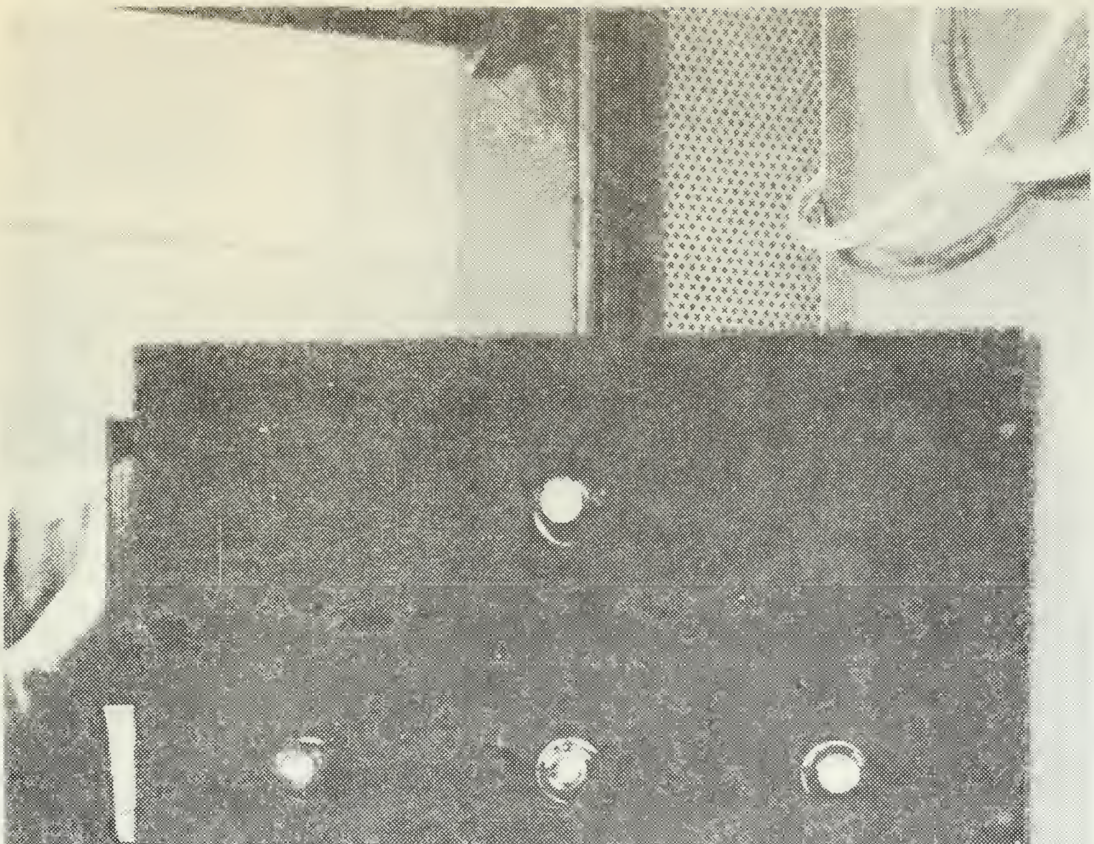


Figure 1.

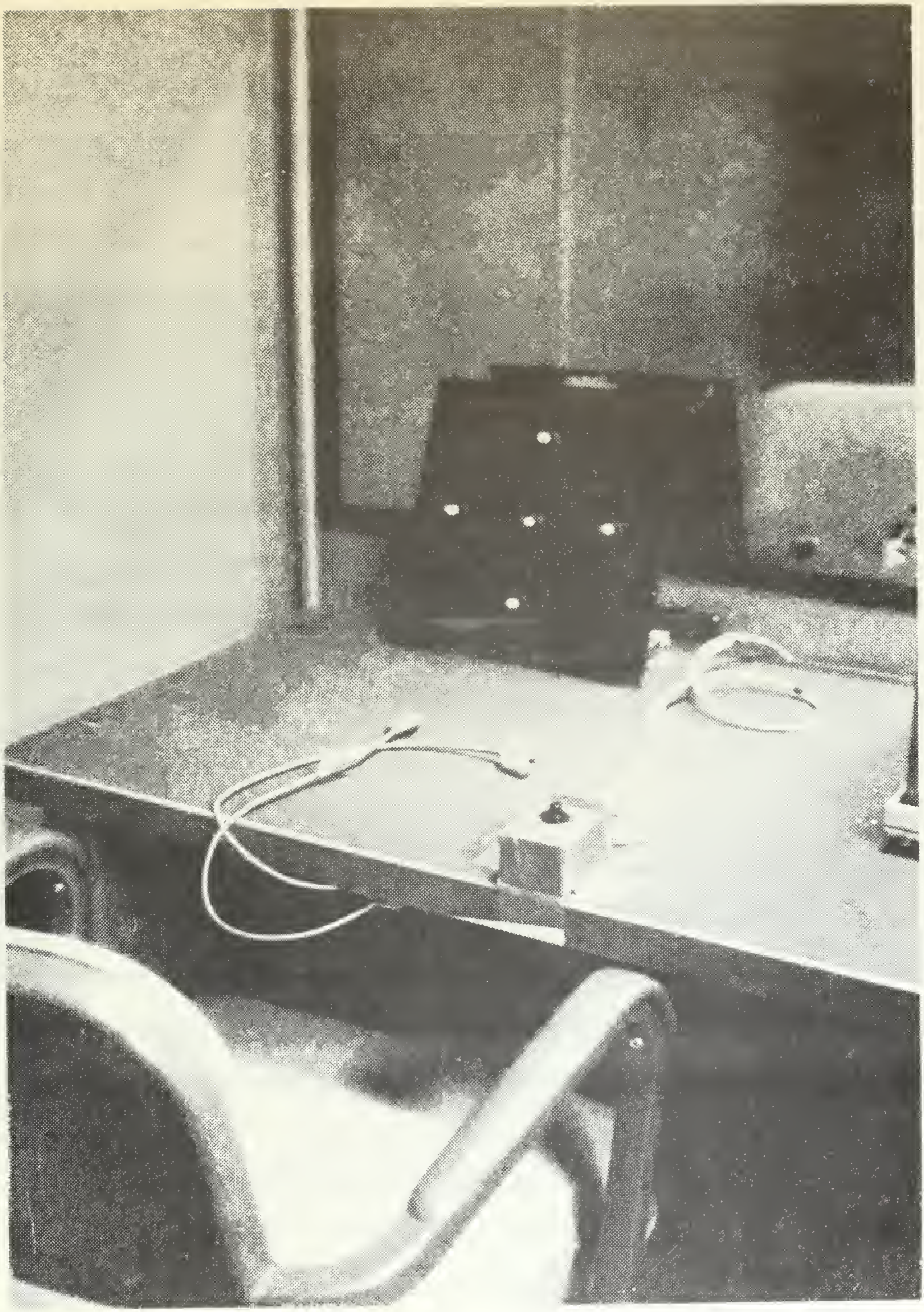


Figure 2.

relays and the adjustable resistance were fabricated by the experimenter. Power to the lights was supplied by a Hewlett-Packard, Model 6216A, Power Supply. Correct responses, incorrect responses, and the number of signals presented were recorded by a Lehigh Valley logic system (Figure 3). Provisions were also made to prevent recording more than one response during any single stimulus period. The elapsed time from the presentation of the signal until a correct response was recorded on a Lafayette Instrument Co. timer for each signal period.

2. Physiological

The myoelectrical potential of the Semispinalis Capitis and Splenius Capitis muscles in the neck was used as the measure of neck muscle tension level [Lippold, 1967]. Two electrodes were placed on the right side of the S's neck. The electrode was placed one and one-eighth inches laterally from the second cervical spine, with the second electrode being placed one and three-fourth inches below the first and seven-eighths inch from the mid-line of the neck (Figure 4). For heart rate, three electrodes were required: one placed below the left breast at the sixth intercostal space; one placed at the top of the sternum; and an indifferent electrode attached over the right hip (Figure 5).

Prior to placing of the electrodes, the skin was cleaned using rubbing alcohol. Beckman Offner electrode paste was placed in each electrode. The electrodes were held in place by Beckman adhesive paper applicators.

The electrical potential signals from the electrodes were processed and graphically recorded by a Beckman Type RM Dynagraph recorder. For future analysis, the processed signals were recorded on magnetic tape by a Hewlett-Packard Model 3960 Instrumentation Recorder. Using

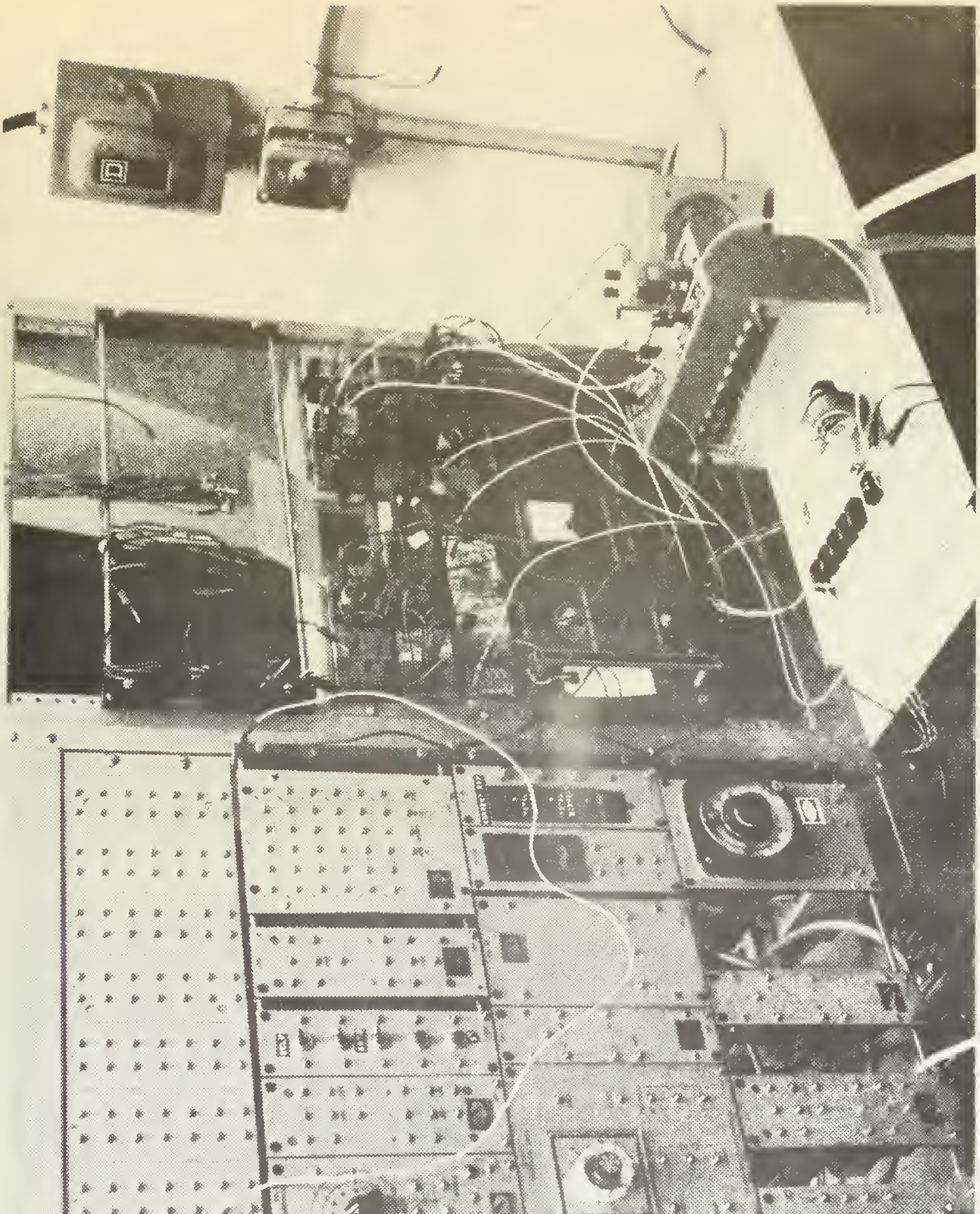


Figure 3.

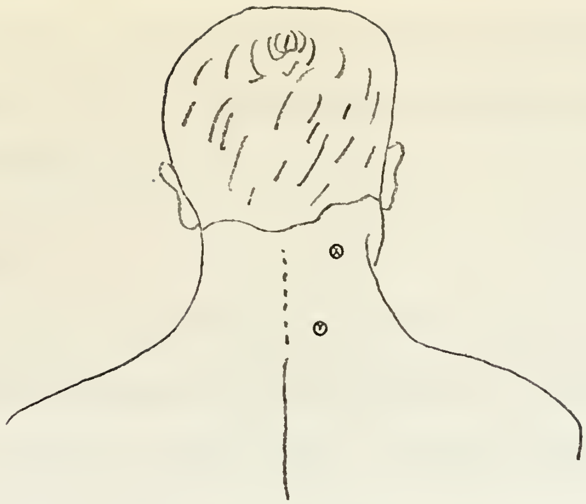


Figure 4. Neck Muscle Tension Electrode Placement

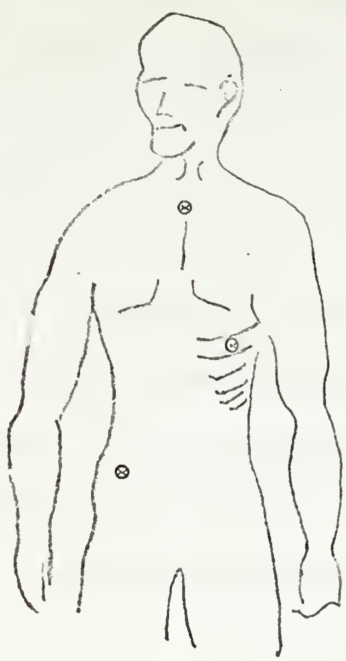


Figure 5. Heart Rate Electrode Placement.

the analog-to-digital multiplex converter of the Digital Corp. LAB/8 digital computer, the signals were analyzed at the time each S was performing the task. The computer analysis provided neck muscle tension level, heart rate, and two measures of sinus arryhthmia for each minute of the experiment.

B. PROCEDURE

At the time of electrode placement, each S received a brief explanation of the function of the electrodes and a description of safety precautions. Each S was then given a sample of the subjective rating checklist and an instruction sheet covering its use (see Appendix A).

The experimenter described the method of response to a signal stimuli and explained the scoring system to be used during the test. The S was then seated in the acoustical chamber and allowed to familiarize himself with the display and response button, while the experimenter connected and calibrated the instrumentation. During the familiarization period, the proportion of signal stimuli was adjusted to 50%. Following the familiarization period, E answered any questions, and the S was given a 15 minute practice session with the signal proportion set at the value to be used during the experiment. At the conclusion of the practice session, questions were answered, and the six 15 minute test sessions began. At the conclusion of each 15 minute session, E entered the chamber and gave the S a subjective rating of fatigue checklist to complete. Immediately upon completion of the checklist, the next testing period began. The interval between test sessions ranged from 60 to 85 seconds in length. Checklists completed by Ss were identical, but the order of the items was different on all but the first and last form to prevent the Ss from unconsciously attempting to be consistant in their responses.

C. REDUCTION OF DATA

At the conclusion of the experiment, there were 90 data points for heart beat rate (HR), neck muscle tension (NMTL), and both measures of sinus arryhthmia (SA and SABS/N), six data points for subjective ratings of fatigue (SFR), average response time (ART), probability of signal detection (PD), probability of false signal detection (PF), and a combined performance measure (SCORE) for each subject. The 90 data points for HR, SA, SABS/N, and NMTL were reduced to six data points per measure for each S by averaging over each 15 minute test session; thus reducing the data to 486 points.

D. MEASURES

HR was computed as the number of R waves within each one minute period, and measured in beats per minute (b.p.m.). Neck muscle tension level was recorded in direct current voltage (vdc). Constant preamplification and amplification settings were maintained for each subject to provide an output within ± one Vdc for compatibility with the LAB/8 computer analog-to-digital converter. Average response time was recorded in seconds per correct response. Each S's responses to the subjective rating of fatigue checklist were scored and then summed for each period. The scoring was on a three point scale: three points for each "better than" response; two points for a "same as" response; and one point for a "worse than" response to each item in the checklist [Pearson and Byars, 1956]. The combined performance measure was computed by obtaining the net difference in PD and PF and then dividing the result by the average response time for each 15 minute session.

The two measures of sinus arryhthmia were computed from the heart rate signals. SABS/N was computed by summing the absolute value of the

differences of the time interval between each set of three successive R waves. The sum was then averaged by dividing by the number of intervals in that one minute period (see Appendix B). The SA measure is the sum of the absolute differences between the heart beat rate for each interval between beats and the actual heart rate for the one minute period (see Appendix B).

III. RESULTS

A graphical representation of the behavior of each parameter over the six test periods is contained in Figures 6, 7, and 8 for combined measures. A treatments-by-subjects, or repeated measures, design analysis of variance (ANOVA) was performed on each parameter and measure of performance to test for significant differences between test periods [Winer, 1962].

The results of these ANOVA's are shown in Tables I through IX. Neck muscle tension level (NMTL), $F(5,40)=4.39$, $p<.005$; SABS/N, $F(5,40)=3.74$, $p<.010$; and PF, $F(5,40)=2.13$, $p<.100$ were the only physiological parameters and measures of performance, respectfully, found to differ significantly between test periods. HR differed between test periods but at $p<.20$, which was not considered significant.

The short length of the test periods, 15 minutes, was felt to be a contributing factor to the lack of significance between test periods. A test for trend over the entire test period would provide a significant indicator of the behavior of the parameters for the full extent of the task. Accordingly, a Wilcoxon signed-ranks test for trend was performed for each parameter and measure of performance using periods one and six [Bruning and Kintz, 1968]. The results of this test are shown in Table X. SA, $p<.05$, and SRF, $p<.02$, were found to show significant trends over the task, as well as NMTL, SABS/N, and PF mentioned above in the analysis of variance.

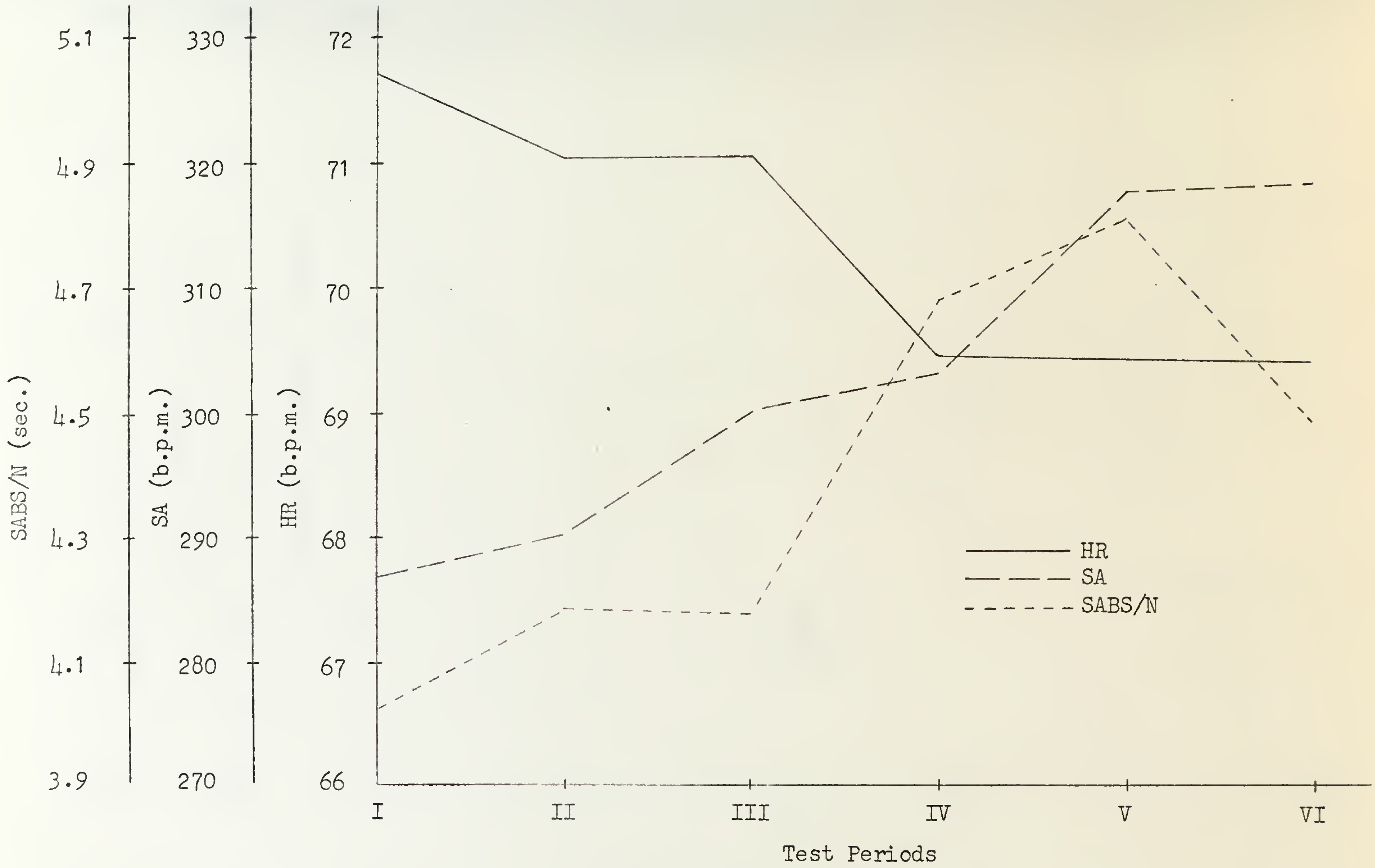

5.1
4.9
4.7
4.5
4.3
4.1
3.9
SABS/N (sec.)
330
320
310
300
290
280
270
SA (b.p.m.)
72
71
70
69
68
67
66
HR (b.p.m.)
I
II
III
IV
V
VI
Test Periods
HR
SA
SABS/N

Figure 6.

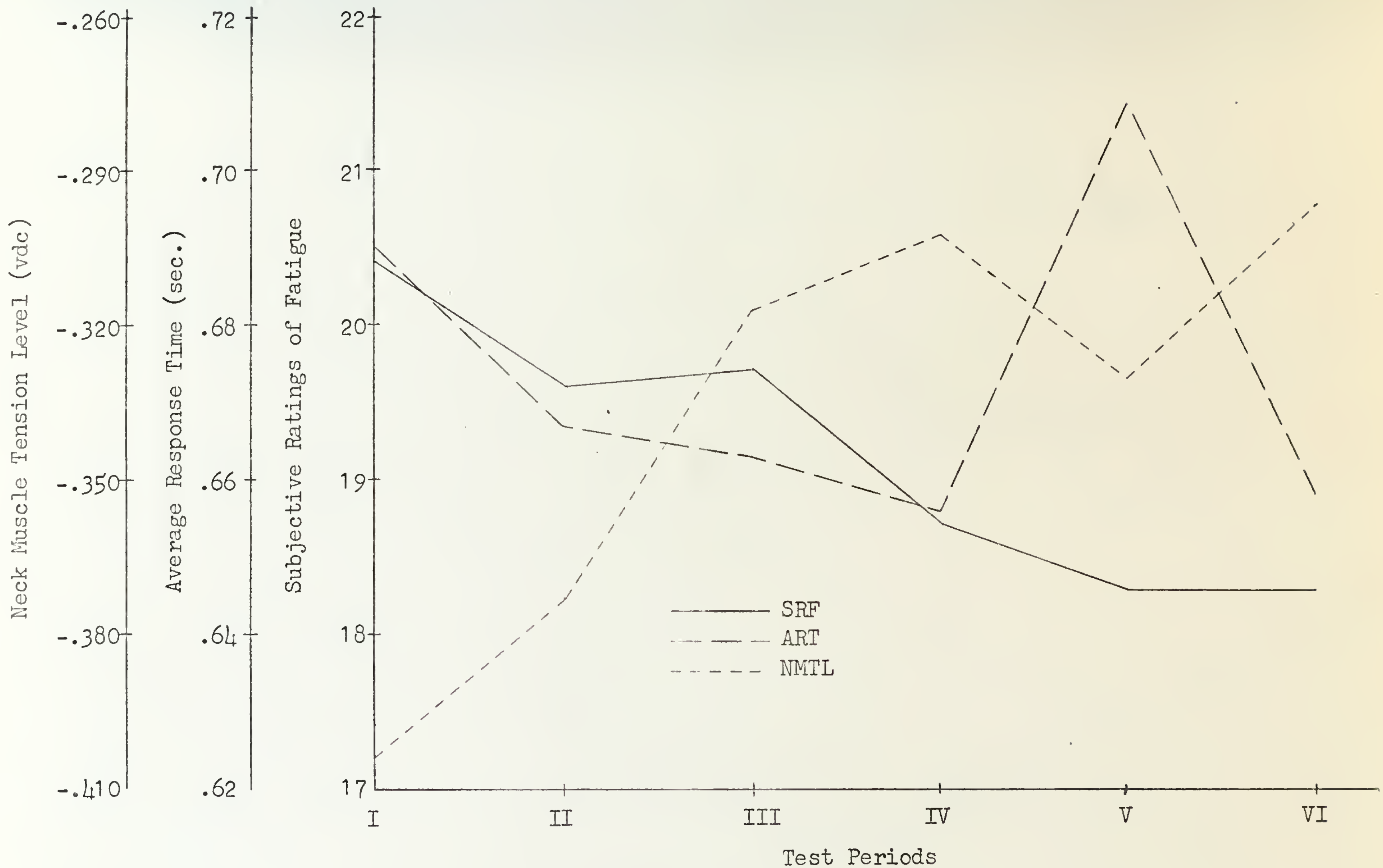

Neck Muscle Tension Level (vdc)
-.260
-.290
-.320
-.350
-.380
-.410
Average Response Time (sec.)
.72
.70
.68
.66
.64
.62
Subjective Ratings of Fatigue
22
21
20
19
18
17
SRF
ART
NMTL
I
II
III
IV
V
VI
Test Periods

Figure 7.

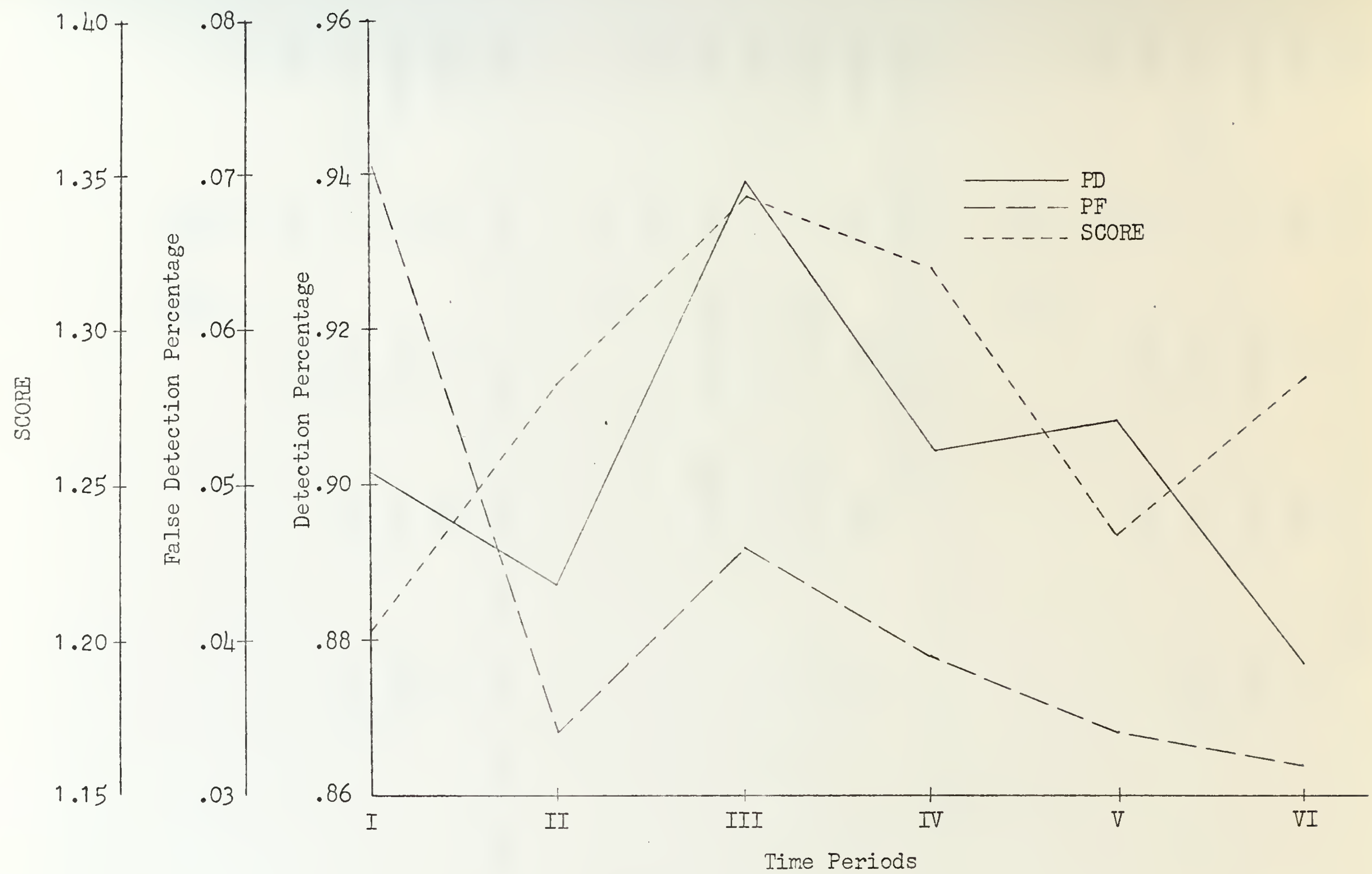

1.40
1.35
1.30
1.25
1.20
1.15
SCORE
.08
.07
.06
.05
.04
.03
False Detection Percentage
.96
.94
.92
.90
.88
.86
Detection Percentage
PD
PF
SCORE
I
II
III
IV
V
VI
Time Periods

Figure 8.

TABLE I. Analysis of Variance on Heart Rate (HR)

Source	df	SS	MS	F
Subjects	8	3596.82	449.60	83.58*
Time periods	5	46.47	9.29	1.73**
Error	40	215.17	5.38	
Total	53			

*p < .001
**p < .20

TABLE II. Analysis of Variance on SA

Source	df	SS	MS	F
Subjects	8	433387.3	54173.42	43.72*
Time periods	5	7775.25	1555.05	1.26
Error	40	49565.69	1239.14	
Total	53			

*p < .001

TABLE III. Analysis of Variance on Neck Muscle Tension Level (NMTL)

Source	df	SS	MS	F
Subjects	8	1.1478	.14347	42.48*
Time periods	5	.0741	.01482	4.39**
Error	40	.1351		
Total	53			

*p < .001
**p < .005

TABLE IV. Analysis of Variance on Subjective Ratings of Fatigue (SRF)

Source	df	SS	MS	F
Subjects	8	29746.21	3718.28	38.85*
Time periods	5	405.50	81.10	.847
Error	40	3828.40	95.71	
Total	53			

*p < .001

TABLE V. Analysis of Variance on Average Response Time (ART)

Source	df	SS	MS	F
Subjects	8	.174	.022	4.145*
Time periods	5	.022	.004	.835
Error	40	.210		
Total	53			

*p < .005

TABLE VI. Analysis of Variance on SABS/N

Source	df	SS	MS	F
Subjects	8	85.85	10.73	46.34*
Time periods	5	4.335	.867	3.744**
Error	40	.232		
Total	53			

*p < .001
**p < .010

TABLE VII. Analysis of Variance on Detection Percentage (PD)

Source	df	SS	MS	F
Subjects	8	.119	.0236	2.535*
Time periods	5	.021	.0041	.440
Error	40	.372		
Total	53			

*p < .025

TABLE VIII. Analysis of Variance on False Detection Percentage (PF)

Source	df	SS	MS	F
Subjects	8	.0970	.0063	6.812*
Time periods	5	.0098	.00197	2.135**
Error	40	.0369	.00092	
Total	53			

*p < .001
**p < .100

TABLE IX. Analysis of Variance on SCORE

Source	df	SS	MS	F
Subjects	8	1.465	.1831	5.089*
Time periods	5	.0793	.0159	.441
Error	40	1.439	.0360	
Total	53			

*p < .005

TABLE X

Results of Wilcoxon Signed-Ranks Test

HR - ns	SRF - $p<.02$	SABS/N - $p<.10$
SA - $p<.05$	ART - ns	SCORE - ns
NMTL - $p<.02$	PD - ns	PF - $p<.05$

Simple linear correlation analysis was conducted to determine any relationships existing between the parameters or between the parameters and the performance measures. To this end, time-on-task was incorporated as the variable TIME PERIODS, and included in the analysis. The results of the correlation analysis are shown in Table XI. Related parameters and performance measures exhibited strong correlations as expected, and additional physiological parameters and performance measures were found to correlate at significant levels. Several of these are: SA vs SRF, $r=-.558$ and HR vs SCORE, $r=.495$. The lack of relationship between TIME PERIODS and other variables was not surprising in light of the earlier analysis of variance and the large differences in basic physiological levels inherent among the Ss. It would be unreasonable to expect high levels of correlation between time periods and any parameters with such large variance in basic levels. For example, the range of HR during the first period was from 57.1 bpm to 84.0 bpm. It seems reasonable to assume that this effect may be observed among psycho-physiological parameters and performance measures as well. Hence, to eliminate the variances in basic levels, all variables were averaged among Ss for each time period.

Results of the subsequent correlation analysis using the mean values are shown in Table XII. The increased level of correlation between TIME PERIODS and the other variables indicate, with the exception of HR, the

	HR	SA	NMTL	SRF	ART	SABS/N	PD	PF	SCORE	TIME PERIODS
HR	1.000	0.528	-0.381	-0.138	-0.502	-0.841	0.388	0.063	0.495	-0.105
SA		1.000	-0.389	-0.558	-0.256	-0.105	0.173	0.058	0.208	0.123
NMTL			1.000	0.015	0.127	0.320	-0.253	0.076	-0.250	0.211
SRF				1.000	0.186	-0.197	-0.055	-0.007	-0.114	-0.288
ART					1.000	0.364	-0.253	-0.029	-0.748	-0.047
SABS/N						1.000	-0.290	-0.087	-0.357	0.165
PD							1.000	-0.068	0.757	-0.044
PF								1.000	-0.265	-0.230
SCORE									1.000	0.052
TIME PERIODS										1.000

TABLE XI. CORRELATION MATRIX (Aggregate Data)

	HR	SA	NMTL	SRF	ART	SABS/N	PD	PF	SCORE	TIME PERIODS
HR	1.000	-0.866	-0.795	0.978	0.054	-0.746	0.268	0.699	-0.174	-0.920
SA		1.000	0.792	-0.900	0.109	0.443	-0.066	-0.578	0.122	0.965
NMTL			1.000	-0.789	-0.444	0.761	0.115	-0.667	0.677	0.852
SRF				1.000	0.022	-0.650	0.295	0.795	-0.172	-0.955
ART					1.000	-0.629	0.114	0.264	-0.779	-0.093
SABS/N						1.000	-0.256	-0.517	0.531	0.604
PD							1.000	0.281	0.402	-0.229
PF								1.000	-0.440	-0.714
SCORE									1.000	0.230
TIME PERIODS										1.000

TABLE XII. CORRELATION MATRIX (Mean Values)

same significance over the entire task as in the Wilcoxon signed-ranks test earlier. The correlation matrix shows a high level of correlation between HR and TIME PERIODS, but the previous tests tend to show that the significance of the correlation is low. The results also indicate a general increase in the correlations between the psycho-physiological parameters. At the same time, the relationships between these variables and measures of performance show varied effects. However, the correlations with PF show a marked improvement. This again verifies earlier results.

Stepwise multiple regression was next employed to inquire into the possible multivariate relationships among and between the physiological parameters and the performance measures. F values for variate inclusion or removal from the regression equation were 3.00 and 1.00, respectfully. Tolerance level for inclusion was 0.30 /Dixon, 1968/. Significant results for both groups of data are indicated in Tables XIII and XIV. The independent variables are shown in their order of inclusion into the regression. The coefficient of determination (R^2) and significance level are for the regression equation upon the inclusion of the independent variable indicated.

As in the correlation analysis, several parameters, when averaged, indicate a significant correlation to time-on-task. In addition, the averaged data exhibit several strong correlations with performance measures. However, with the exception of SCORE, the stepwise regression with the mean values did not identify multivariate relationships. This is in part due to the reduced degrees of freedom allowed the regression equation from the smaller sample size, and, of necessity, restricts the effectiveness of the multiple regression.

TABLE XIII

RESULTS OF STEPWISE MULTIPLE REGRESSION (Aggregate)

Dependent Variable	Independent Variable(s)	R^2	F	p<
HR	SABS/N	.71	125.23	.001
	SA	.90	235.67	.001
SA	SRF	.31	23.54	.001
	HR	.52	27.52	.001
NMTL	SA	.15	9.20	.005
	SABS/N	.23	7.60	.005
SRF	SA	.31	23.54	.001
	SABS/N	.37	15.54	.001
ART	HR	.25	17.56	.001
SABS/N	HR	.71	125.23	.001
	SA	.87	164.91	.001
PD	HR	.15	9.24	.005
SCORE	HR	.24	16.89	.001

TABLE XIV

RESULTS OF STEPWISE MULTIPLE REGRESSION (Mean Values)

Dependent Variable	Independent Variable(s)	R^2	F	p<
HR	SRF	.96	86.46	.001
SA	TIME PERIODS	.93	54.42	.005
NMTL	TIME PERIODS	.73	10.61	.050
SRF	HR	.96	86.46	.001
SABS/N	NTL	.58	5.51	.100
PF	SRF	.63	6.85	.100
SCORE	NTL	.46	3.38	.200
	SA	.92	17.00	.025
	SABS/N	.99	107.68	.001

Several significant multivariate correlations resulted from the stepwise regression among the variables when using the aggregate data. The coefficients of determination (R^2) and level of significance of these relationships are even more noteworthy considering the large between-subject variance mentioned above. The correlations between physiological parameters and performance were limited to HR at somewhat lower levels of correlation and significance.

IV. DISCUSSION AND CONCLUSIONS

This research has shown evidence of simple and multivariate correlations between physiological indicators, performance measures, and subjective assessments of fatigue. That levels of physiological activity were found to correlate with performance is in agreement with the basis for the Arousal Theory of vigilance performance which associates decreased performance with concurrent reduced physiological activity. Addition of the correlation of subjective assessments of fatigue to physiological activity levels and to performance suggests that a more complex combination of factors may underlie the mechanism of vigilance performance.

Increasing levels of heart beat irregularity, during the length of the task, provide a basis for additional inferences concerning information processing and sinus arryhthmia. The task performed in the experiment was designed to maintain a constant level of information processing in the attempt to more fully isolate the effects of motivation on sinus arryhthmia. The observed positive correlation of the two measures of arryhthmia with performance can be viewed as an indicator of motivation level and to be responsive to the S's perception of the difficulty of the task. Hence, sinus arryhthmia measures may be sensitive to information processing levels or mental loading and to the natural tendency to "try harder" on the more difficult tasks. This is supported, in part, by the results of Bonsper (1970) and Douglas (1972). Both experiments were designed such that the mental loading increased as the experiment progressed. In each case the measures of sinus arryhthmia decreased with increased loading and time-on-task in contrast

with the observed increase in the present investigation. Hence, it can be postulated that the decrease in sinus arryhthmia was a result of both the increased loading and an increase in motivation countering the effects of fatigue and boredom. This position is supported by the increase in heart rate which can be considered indicative of an increased level of physiological activity.

The characteristic tendency for physiological activity to decrease over the length of a vigil was supported by the observations of this experiment. As such, the high multivariate intra-parameter correlations were not unexpected. More importantly, the similar behavior of subjective ratings poses the question as to the controlling mechanism for these indicators. That is, the subjective ratings, or S's state of mind, can be considered as a reflection of his physiological level. While on the other hand, his perception of the difficulty of the task, his interest in it, and his level of motivation may shape his subjective feelings of fatigue and, in turn, control the level of physiological activity. In either case the importance of subjective ratings as an indicator of vigilance performance and physiological activity seems implied in the vigilance task.

Examination of the data outside the formal statistical analysis presents further support of the validity of subjective ratings in the vigilance task. The results depicted in Figures 6, 7, and 8 for the fourth and fifth test periods indicate that at the end of the fourth period, a performance decrement was in evidence as indicated by the sharp drops in PD and SCORE. The subjective ratings also indicate a large increase in feelings of fatigue in the period. Comments made to E by the subjects while filling out the checklists indicated that

they were aware of the decrement in detections, and would be trying harder during the next period. Subsequently, during the fifth test period PD did not decrease, but in fact improved slightly. The improvement in PD was obtained at the expense of reaction time, implying that more care was taken in evaluating each of the stimulus signals. The sharp increase in NMTL and SABS/N, and the decrease in rate of change in SRF indicate high levels of activation. During the sixth period there was a return to the pattern of performance deterioration and decrease in arousal indicators.

In application of the results of this experiment, it should be considered that the time-related patterns of the physiological parameters and performance measures are based on mean values and, therefore, reflect the aggregate of the subjects' responses. Thus, it cannot be asserted that the relationships are specifically predictive of that of an individual. The same caution in predictive use can be made for the statistical results obtained from the ungrouped data. In this case, the large between-subject variance characteristic of physiological responses limits the application of results to the identification of intra-parameter and performance correlates as opposed to individual predictive associations.

The twofold purpose of the experiment was to identify basic correlates among psycho-physiological parameters and to provide vigilance performance correlates. Results concerning the former have been discussed above. With the exception of the multivariate relationship between SCORE and NMTL, SA, and SABS/N, correlates of performance identified proved statistically significant but at a low correlation. This is in part due to the relative lack of performance degradation realized over the vigil. Contributing to this high level of performance

was the ease of the task, i.e; a large differential intensity between signal and non-signal stimuli. Increasing the task difficulty by providing less differential intensity or extending the length of the vigil should provide a more typical performance degradation. This would allow more definitive analysis of performance correlates.

In summary, this research has provided support for the Arousal Theory of vigilance performance in the behavior of observed physiological parameters. The correlation show by subjective ratings of fatigue to the physiological parameters and to measures of performance extend the use of a self-perceived measure of performance to the vigilance task. These findings also suggest the need for additional research into the motivation-sinus arryhthmia relationship for the purpose of defining the nature of the association.

APPENDIX A

CHECKLIST INSTRUCTIONS

The statements in the short checklist are to help you decide how you feel at the time you fill out the checklist. When filling out checklists during the experiment, the desired response will be how you feel right then - not how you felt an hour prior, and not how you felt yesterday.

For each statement you must determine whether you feel: (1) "Better Than," (2) "Same As," or (3) "Worse Than" the feeling described by that statement.

As an example, take a person who feels a little tired. He might respond to the following items as follows:

	Better Than	Same As	Worse Than	Statement
1.	( )	( )	(X)	Extremely Fresh
2.	( )	(X)	( )	Slightly Tired
3.	(X)	( )	( )	Completely Exhausted

In other words, this person feels worse than "Extremely Fresh," about the same as "Slightly Tired," but, on the other hand, better than "Completely Exhausted."

Take each statement in order. Do not skip around from one to another. Read each statement carefully, so that you understand what it means; then indicate how you feel at that instant, relative to that statement, by placing a check in the appropriate response space.

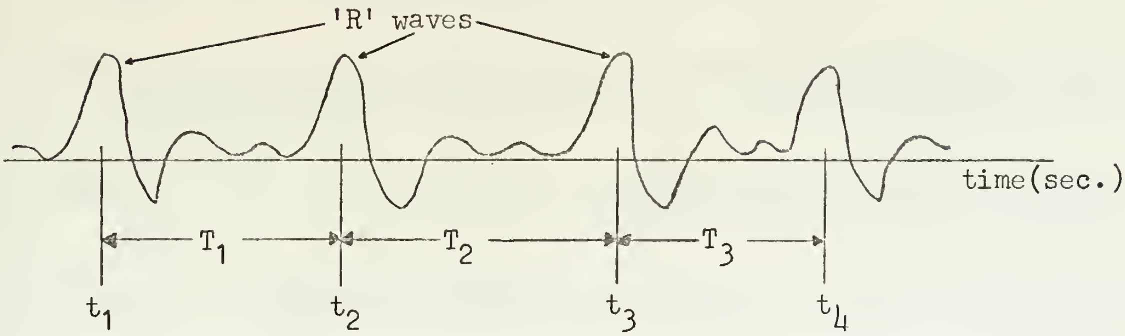
This is not a test. There are no correct or incorrect responses. The checklist is to help you decide how you feel at that point in the experiment. Take your time, and indicate your response to each statement.

Below is an example of a checklist:

No.	Better Than	Same As	Worse Than	Statement
1.	( )	( )	( )	quite fresh
2.	( )	( )	( )	petered out
3.	( )	( )	( )	very refreshed
4.	( )	( )	( )	extremely tired
5.	( )	( )	( )	fairly well pooped
6.	( )	( )	( )	extremely peppy
7.	( )	( )	( )	ready to drop
8.	( )	( )	( )	very lively
9.	( )	( )	( )	slightly pooped
10.	( )	( )	( )	somewhat fresh

APPENDIX B

MEASURES OF SINUS ARRYHTHMIA



$$SA_j = \sum_{i=1}^{M-1} \left| \frac{60}{t_{i+1} - t_i} - HR_j \right|$$, where M=number of 'R' waves in the j-th minute and HR_j is the heart rate for the j-th minute.

$$SA_i = \sum_{n=1}^{15} \frac{SA_n}{15}$$, the average SA for the i-th test period, i=1,2,3,4,5,6.

$$SABS/N_j = \sum_{i=1}^{M-1} \frac{\left| T_{i+1} - T_i \right|}{M-1}$$, where M=number of 'R' waves in the j-th minute.

$$SABS/N_i = \sum_{n=1}^{15} \frac{SABS/N_n}{15}$$, the average SABS/N for the i-th test period, i=1,2,3,4,5,6.

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Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

ORIGINATING ACTIVITY (Corporate author) Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

REPORT TITLE

Subjective and Physiological Indicators of Fatigue in a Vigilance Task

DESCRIPTIVE NOTES (Type of report and, inclusive dates)

Master's Thesis, March 1973

AUTHOR(S) (First name, middle initial, last name)

Henry Edgar Innes

REPORT DATE March 1973	7a. TOTAL NO. OF PAGES 43	7b. NO. OF REFS 18
CONTRACT OR GRANT NO. PROJECT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	

DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Postgraduate School Monterey, California 93940

ABSTRACT

This research represents an investigation to determine intra-correlations among physiological parameters, a subjective rating of fatigue and performance during a vigilance task. Simple and multivariate analyses indicate positive relationships between subjective ratings of fatigue and heart rate, neck muscle tension level and two measures of sinus arryhthmia. Subjective ratings were found to correlate with time-on-task. Effects of motivation on sinus arryhthmia are discussed in the context of information processing. Single variate correlations between performance and heart rate, as well as with subjective ratings of fatigue, were observed with significant but low correlation coefficients. Multivariate correlation of neck muscle tension level and sinus arryhthmia were found to be significantly correlated with performance.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Vigilance						
Monitoring.						
Subjective Fatigue						
Sinus Arryhthmia						
Heart Rate						
Muscle Tension						

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